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ABRASIVE AND INDUSTRIAL DIAMONDS

BY

PAUL M. TYLER

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

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By Paul M. Tyler [2]

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FOREWORD

In preparing this paper the writer has perforce depended mainly upon published information, including the catalogs and pamphlets issued by importers and dealers such as the Diamond Drill Carbon Co. and J. K. Smit & Zonen. Special acknowledgment is made to various articles published by S. H. Ball. The writer of this paper, however, is alone responsible for statements herein contained and since he has often found it necessary to rationalize apparently conflicting opinions of recognized authorities on this little-known subject, he will welcome constructive criticism from the trade.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6562."

[2] Chief engineer, rare metals and nonmetals division, U. S. Bureau of Mines.

ABRASIVE AND INDUSTRIAL DIAMONDS

GENERAL DESCRIPTION

Two types of diamond are extensively used for industrial purposes. One type, known as bort or bortz (boort, boart, bowr, etc.), consists of diamonds of the gem variety but unfit for cutting into gems. They may be colorless, yellow, brown, or gray. The other type, carbonado, known in the trade as "carbon" or "black diamond," differs greatly from the white diamond, being opaque and apparently amorphous or noncrystalline. Actually, instead of forming a large single crystal as in a gem stone, carbon diamond comprises a mass of microscopic crystals that interlock to form a tough, homogeneous material with no planes of cleavage. It is found in various colors -- black, dark green, brown, and gray -- but usually it has a dark lustrous black surface, with a resinoid or submetallic appearance, often resembling fine-grained steel. Upon exposure to the air the broken surface gradually darkens to an ash-gray color. Ballas is a special type of carbonado in which the crystals are definitely oriented around a central nucleus. They are harder and tougher than ordinary carbonado but are much scarcer. The Cape ballas is reputed to be not quite so tough as Brazilian ballas but tougher than carbon or bort.

The diamond crystals are isometric and take a variety of forms. The cleavage is octahedral and well marked. A crack is easily started parallel to an octahedral face, and bort or gem diamonds are notoriously brittle, especially when subjected to sudden shock. Even carbonado, while it has a high resistance to slowly applied pressures, may be chipped or broken by a sharp blow.

Exposed to radioactive rays, the diamond becomes phosphorescent; this property is often utilized to distinguish it from quartz, topaz, or glass. The unusually high refractive index likewise aids in its identification in the case of a more or less transparent stone. At the temperature of the electric arc, diamond is converted into graphite, another form of carbon but one of the softest mineral substances. At a much lower temperature, as low as 1,562° F., the diamond may be burned like ordinary carbon in an atmosphere of oxygen, and according to some authorities there is danger of burning a diamond if overheated even in air.

The diamond is the hardest known substance. It is numbered 10 on the Mohs scale. Sapphire is numbered 9 on the same scale, but the difference in hardness bears no corresponding numerical relationship. In fact, the diamond is probably at least 10 times as hard as the sapphire (corundum). It has been stated that in reality there is no difference in the hardness of different varieties of diamonds (except the slight advantage of a pure white stone over one of a deeper color) and that differences in the apparent hardness are a function of porosity. The specific gravity is often a guide to the effective hardness, though not always. In general, carbons having a specific gravity of 3.30 to 3.10 are of superior quality; those of 3.10 to 3.00 of good quality; those of 3.00 to 2.90 of medium quality; and those below 2.90 of inferior quality. Gem diamonds are heavier, the specific gravity usually being given as 3.50 to 3.52. The only sure test of hardness, however, is by means of the Brazilian ballas stone in the hands of an expert. A white mark following the test scratch indicates that the carbon is harder than the ballas and a dark brown mark indicates that the ballas is harder; no mark at all indicates that both are equally hard. The sound given off when making the test scratch is also an indication. The appearance of a fractured surface likewise may afford a criterion of quality, a close-grained, steel-like fracture being preferable to a porous, coarse grain.

Carbons are graded according to their hardness, and the trade also distinguishes between natural stones and split stones. The natural stones are possessed of a tough skin which offers great resistance to wear.

Borts are divided into many classes.[3] According to color they may be designated as white, gray, black, light brown, dark brown, canary yellow, pink, and green. They may be further subdivided as "selected," "finest selected," etc. Shapes are likewise differentiated -- octahedron, round, flat, bullnose, irregular, and cleavage. The octahedron, for example, is an excellent shape for the stone setter to handle, but even a round diamond can be held firmly in place if properly set. The claim is made that a stone furnishing the greatest number of sharp points will give most service but many authorities are of the opinion that round or "bullnose" stones will give greater service, provided they are reset frequently. Names designating the origin or the producing mine are also employed. Brazilian stones are generally harder than Cape diamonds and Australian and South West African borts are intermediate. According to industrial application, borts may be classified as follows:

Crushing Bort.[4] - Pieces of diamonds, incompletely crystallized, broken, opaque or cloudy, and all fragments unsuited for decorative or industrial purposes are classed as crushing bort. This bort is pulverized and used as a cutting and polishing medium for brilliants and other precious stones, as a drilling medium in the manufacture of diamond dies, and as a sawing medium for porcelain, etc.

Round crushing bort is preferred, and of this the Brazilian is most desirable. Its superior quality is due to the fact that each single, minute crystal is provided with a tough sheath or skin, which makes it stand up better to the work. Polishers are advised to buy their own bort and pulverize it in a mortar, as ordinary commercial diamond dust is usually greatly adulterated with cement and therefore of poor quality.

Splints. - The splints which accumulate when cleaving diamonds are assorted into coarse, middle, and fine grades. Prudence should be observed when purchasing splints, which should only be bought from firms guaranteeing 100 per cent pure diamond. Unscrupulous dealers add foreign matter in proportions up to 40

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3 - Sansom, W. J., Industrial Diamond Nomenclature: Abrasive Industry, vol. 4, February, 1923, pp. 49-50.

4 - Anton Smit & Co. (Selma Mercantile Corporation, Agents, New York, N. Y.). Catalog. Diamonds for Industrial Purposes, p. 11.

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and 50 per cent, which although relatively hard, costs scarcely anything, and thus explains the cheapness of this substitute. Splints are used mainly by optical and glass works and for truing small grinding wheels such as are used by dentists.

Diamond Points.[5] As their name implies, diamond points are elongated thin stones, and may be obtained in the natural state, cleaved, sawn, or polished. They are used for drilling glass, for graduating measuring and astronomical instruments, and for graving tools of different kinds.

Saw Bort. - Saw bort is used as the cutting agent in saw teeth for sawing stone. Circular saws of this type, using 1/2 to 1 carat bort or carbons, are more common than drag saws. In the United States they are widely used only in the marble and limestone industries, although a diamond saw recently tried out in the slate industry has proved a success.

Drilling Bort. - The grade of bort used in the diamond core drills for mining and prospecting is called drilling bort.

Slabs. - Slabs are a type of bort used in turning tools.

Die Bort. - Die bort is set in brass or steel holders and pierced for drawing fine wire. Rather flattish stones are used, and hardness at the centre where the wear takes place is essential. The diamonds are pierced by means of fine steel needles charged with diamond dust and oil.

Grinders. - Grinders are stones set in holders for truing grinding wheels.

Glaziers (vitriers). - Very small borts, as many as 80 to the carat, are used for cutting glass and are called glaziers or vitriers. In general those with a naturally curved edge are preferred. They are set in copper or brass.

USES

The uses of diamonds for purposes other than jewelry depend upon their extreme hardness. Diamond dust has always been the only material used for cutting or engraving the diamond itself, and the employment of powdered bort and the lapidary's wheel dates back at least to 1478 when it was used in Belgium. Later, bort came to be used for cutting and drilling glass and porcelain and for fine engraving and drilling tools, and in turning tools for electric-light carbons, hard rubber, etc. Diamonds have also been used like sapphires for bearings in watches and meters.

Carbons are used chiefly in rock drills and prospecting operations, for truing abrasive wheels, and to a less extent for wire drawing dies, specially shaped tools for working metals, and for stone saws. Because of their lower cost, borts are probably used to an even larger extent than carbons for dressing abrasive wheels and this is by far the chief use, but they are also used

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5 - Anton Smit & Co. (Selma Mercantile Corp., Agents, New York, N. Y.), Catalog. Diamonds for Industrial Purposes, p. 11.

occasionally in rock drills and almost exclusively for the various miscellaneous purposes including wire drawing, stone sawing, glass cutting, and shaped diamond tools.

During 1930, according to a report circulated by J. K. Smit & Zonen of Amsterdam, the demand for industrial diamonds for truing emery wheels decreased by about one-third as a result of the general industrial situation. Competition from tungsten carbide and other superhard materials has reduced the consumption of diamonds for wire drawing dies, but diamonds are still used extensively in small dies, especially for drawing the fine copper wire used in great quantities by the radio industry.

Diamond Drilling. - The diamond drill has long been one of the important tools used in prospecting and for the delineation of orebodies. More recently they have come to be used for sampling and exploring nonmetallic mineral deposits and for borings to test foundations of bridges, dams, and permanent structures and to investigate suitable locations for tunnels and underground conduits. They have also been used to provide ventilation to underground workings and to introduce water in order to extinguish mine fires. An outstanding advantage of the diamond drill is that it generally produces for examination a core or cylindrical section of the actual formation which is passed through. The size of core will vary from less than 1 inch to 4 inches or more in diameter, depending upon the type of machine chosen for the work. Diamond drilling is sometimes used for rather shallow holes, but holes of 6,000 feet or more can be drilled successfully.

The rate of drilling depends upon the nature of the formation, averaging between 30 and 50 feet in granite and increasing to 100 or 200 feet a day in soft formations. The cost of diamond drilling likewise varies greatly; the range is from a minimum of about $1.25 up to $10 or more per foot with the average contract rate somewhere between $2 and $4 a foot, depending upon the nature of the ground and the locality.

The diamonds are set at equal distances around the face of a hollow crown or bit which is revolved rapidly by means of a system of hollow rods driven from a rig set up outside the hole. The cuttings are swept out by a stream of water, and as drilling progresses, the core is received into a core tube from which it is recovered from time to time as the rods are withdrawn from the hole. For very small holes only 4 diamonds may be used, but usually 6 or 8 and occasionally 10 stones are employed. The size depends on the diameter of the crown; the range is from 1/2 to 8 carats, but stones of 2 to 6 carats are generally employed. Each diamond covers slightly more than half the thickness of the wall of the crown. Often 2 or 4 diamonds are set halfway up, around the inside and outside faces of the crown; these serve as reamers and thereby provide additional clearance, reduce wear, and roduce sticking of the core. Carbons are chiefly employed for diamond drilling but borts, since they cost only about one-fourth as much, have long been employed in medium-hard to soft formations, and more recently at least one company has devised a system of using a large number of small diamonds forming virtually an incrustation covering the cutting face of the bit. By this new method the stresses, instead of being absorbed at 6 or 8 points, are distributed over 50 or 75 points, none of which is so severely taxed. Since small stones are much cheaper per carat than large stones and since bort can be used instead of carbons for even hard rock, the saving in cost is obvious. This new type of crown, using crystalline diamonds, is claimed to drill faster as well as to be cheaper to install and to operate.

The consumption of diamonds in diamond drilling is estimated at 5,000 to 10,000 carats annually, depending upon general business conditions.

Truing Grinding Wheels. - With the increasing employment of abrasive wheels for accurate finishing of automobile parts, a larger and larger demand has been created for diamond dressing tools for keeping the wheels in true cylindrical shape, as well as for restoring the cutting surface as it becomes glazed and filled with dust. Cape and Brazilian borts and ballas are chiefly used but despite their higher cost, carbons are likewise employed, especially for dry wheels. The size of diamond depends on the size of the wheel; for a 6-inch wheel a 1/2-carat stone may be used, but for a 36-inch wheel manufacturers are likely to recommend a 3-carat stone. Width of face and the grain or "grit" are also taken into consideration, a coarse-grained wheel calling for a larger stone than a fine-grained wheel.

Turning Tools, etc. - Many tough, fibrous materials, though not particularly hard, can not be machined satisfactorily with steel tools, as the heat developed soon ruins the cutting edge. Turning tool bits tipped with shaped diamonds, on the other hand, will work the toughest material continuously sometimes for months without requiring to be re-dressed. The turning of hard-rubber fountain pen cases, which involves the most accurate fitting, and the truing of "felt" rolls used in paper mills are likely to be done by diamond-pointed tools, and such tools are also employed for forming and finishing ivory, built-up mica, graphite compositions, vulcanized fiber, synthetic phenolic resins and similar plastics, papier mâché, and even some of the nonferrous metals, notably the harder bronze alloys, aluminum, and copper. Carbon is often recommended for such purposes because as compared to bort, it is more readily shaped (being noncrystalline) and has better wearing qualities.

Wire Drawing Dies. - According to Ball,[6] one of the principal uses of industrial diamonds is for wire dies. The value of diamond dies sold annually in the United States is said to approximate $3,000,000, and a further $2,500,000 is spent yearly for dies in Europe. The cost of a die is made up about as follows: Stone, 40 to 46 per cent; diamond dust used in grinding, 22 to 30 per cent; and labor, 30 to 32 per cent. The first patent covering diamond dies was taken out by Brokedo in England in 1819, although dies were not used commercially until 1868. The first use of such dies in the United States was at Wallace & Sons' plant at Ansonia, Conn., now owned by the American Brass Co. The stones used are cleavage plates or thin crystals ("flats") and ballas. They weigh from a half carat to 10 carats. A hole, tapered at either end, is started in

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6 - Ball, S. H., Industrial Uses of Diamonds: Eng. and Min. Jour.-Press, vol. 119, May 23, 1925, p. 849.

a thin fragment of diamond by a diamond point and is finished by a steel drill fed with diamond dust; the process is a long and tedious one. The small plate of diamond is then mounted in a brass or Monel metal disk. When by use the aperture of a die is enlarged, it is re-drilled to draw the next larger size of wire. The average life of a die is about two years, the extremes of usefulness being a few weeks and 25 years. The die produces a wire of uniform size and high polish, even when of very fine gage. The wires drawn vary in diameter from 0.114 inch (2.9 mm.) to 0.0008 inch (0.02 mm.), although holes as small as 0.0004 inch (0.01 mm.) have been used. In drawing fine wire, several successively smaller dies are used, and in some instances, at least, the diamond die is used only in the last drawing. Owing to the high cost of such dies, other hard stone or alloy-steel dies are frequently used for the coarser work.

Dies are made principally in the United States, France, and Germany, and recently their manufacture was begun in Japan. In America some of the larger wire manufacturers make their own dies. Because of the expected prosperity of the electrical industry, the use of dies will undoubtedly increase greatly within the next few years. In making tantalum, tungsten, and osmium filaments for electric lamps, the metal is said to be heated to 300 to 400° C. before drawing. Copper, gold, silver, brass, bronze, iron, platinum, Monel metal, nickel, and crucible-steel wires are also drawn through diamond dies. The metals are named in the order in which they wear the dies, and in the case of the harder metal the diamond consumption is high. From 300 to 400 tons of copper wire can be drawn through a single die without variation in gage.

Glass Cutting.[7] - In the sixteenth and seventeenth centuries, diamond crystals were set in rings with one of the points exposed, and these were used to engrave wine glasses and looking glasses. People then in high society used such rings to inscribe poetry on glass windows, the first recorded user being Francis I of France (1494 to 1547). Queen Elizabeth and Sir Walter Raleigh wrote verse to each other in this manner.

Natural crystals alone satisfactorily cut glass so that it breaks along the groove so produced. The cutting edge is formed by markedly curved faces, meeting in a not too obtuse angle, the curved rhombic dodecahedron being particularly satisfactory, but octahedrons are also used. The stones used, frequently of gem quality, are small and vary in size from 1/80 to ¼ carat, most of them approximating 30 to the carat. The majority of glaziers' diamonds come from Brazil and Borneo; good stones are scarce and the price is high (about $40 per carat). The diamond is set in a fusible metal, to which is attached a handle. Once an edge is dulled, the stones are reset in the tool. In addition to the cutting of window panes, the edges and ends of rolled plate glass from the annealing kiln are trimmed with a diamond of adequate size. Although a small quantity of stones is employed for this purpose, it is one of the most familiar uses of diamonds.

Diamond Points.[8] - When diamonds are crushed for dust, sharp fragments are picked out, and these, together with sharp natural crystals and artificially shaped points of carbonado or bort, are used for many purposes, among them being:

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[7] - Ball, S. H., Work cited, p. 850.
[8] - Ball, S. H., Work cited, p. 850.

1. In cleaving diamonds, a diamond with acute edge called a "sharp" is used to cut a depression into which a blunt steel knife is later inserted. Cleaving was known both in India and in Europe at least early in the seventeenth century. In Europe, the art was lost, only to be rediscovered by Dr. William H. Wallaston, in the eighteenth century. He made a modest fortune by cleaving poorly shaped or spotted diamonds.

2. The use of diamond points set in drills is widespread, particularly in boring holes in watch jewels, in drilling eyeglass lenses, in piercing pottery to be repaired, in drilling holes in porcelain teeth, and in drilling holes in other precious stones, as in agates at Oberstein. Extreme accuracy of gage is obtainable.

3. Much fine etching (the engraving of divisions on balances, glass engraving, sketching designs on precious stones before engraving and lithographing) is done with a diamond point.

4. In cutting the deeper depressions for intaglios, a diamond point is still used.

Miscellaneous Use.[9] - The pivot supports of high-grade chronometers and other delicate instruments are sometimes made of diamonds, but the cost of the material and workmanship is, except in rare instances, prohibitive. Diamonds are also used for bearings of large-capacity electric meters and for balances. At present, five American firms manufacture gramophone diamond reproducing points. Small pieces of bort are turned with a diamond tool into a cone about 3/32 inch long, which is set in a brass or nickel shank.

A ballas set in a holder is used by some diamond-drill firms to test hardness in selecting carbonado. Bort and carbonado are also set in instruments with which the radiating sharp-edged furrows on the grinding surfaces of millstones are cut. It is reported that, in instances, bort is used in brutting diamonds, but for this purpose both stones employed are usually gems.

Obsolete Uses.[10] - About 1825, Pritchard cut diamond lenses, but the optical anomalies disclosed and the cost of manufacture proved the stone unsuitable for this use. By cleaving gem diamonds, thin transparent guardcovers for miniatures are produced. At Queen Victoria's coronation, certain of the guests were given the Queen's likeness protected by a film of transparent diamond. In Shantung, China, the diamond is reported to have been used at times as currency, and such was the case to a limited extent at least in the eighteenth century in Minas Geraes, Brazil.

Diamond dust, formerly used in polishing granite and other building stones, has been largely supplanted by "Carborundum" and other abrasives. Sixty years ago, channelers and gadders set with carbonado were widely used in the marble quarries in New York and Vermont.

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[9] - Ball, S. H., Work cited, p. 850.
[10] - Ball, S. H., Work cited, p. 850.

In the Middle Ages, a diet of diamond dust was a supposedly efficacious method of disposing of one's enemies.

SUBSTITUTES

Since the diamond is the hardest substance known to man, it has no perfect substitute and, broadly speaking, the only reason for using other materials instead is because they are cheaper.

In recent years there has been a rapid development in the production of ultrahard alloys and metallic mixtures, including stellite and tungsten carbide. Turning tools of these materials have been used to some extent to replace diamond-pointed tools. In oil-well drilling, principally in fairly soft formations, cutters pointed with fragments of tungsten alloys (cf. "Borium") have been used, and processes for applying stellite and other hard alloys to wearing surfaces have considerably extended the field of use of rotary cutters and other drilling tools that do not employ diamonds. It is doubtful, however, if these invasions have effected any large reduction in the use of diamond drills. In this field, the leading development has been the partial substitution of white diamonds for carbonados, as elsewhere mentioned.

For truing abrasive wheels other arrangements have been proposed but with no substantial reduction resulting in the use of diamonds.

In the stone industry "Carborundum" dust has replaced diamond dust for polishing, and instead of diamond saws, steel saws (charged with sand or steel shot) and"Carborundum" saws are widely used.

HISTORY

Since the natural beauties of the gem diamond are not revealed except by cutting, this variety was not highly prized by the ancients; the popularity of the precious stone virtually dates from the discovery that diamond will cut diamond. In other words, it was the utilitarian properties of the mineral that made possible its primacy in the field of personal adornment and display. The use of diamond graving tools is of great antiquity. Due to its hardness and imperishable nature, legends sprang up around the stone and, as it was credited with sundry supernatural virtues, it even found its way into medieval nostrums and sorcerer's charms. Tradition credits Robert de Berquem (also Ludwig von Berquen) of Bruges with the invention of diamond cutting in 1478, but there are evidences that the art was practiced in Paris by a guild of "diamond polishers" headed by a certain Herrmann as early as 1300.[11] Long before that the Indian lapidaries had learned to polish the natural faces of well-shaped crystals ("points natifs") with diamond dust. The fact that the diamond could be split was likewise known to the early Indian lapidaries and perhaps in Europe in the sixteenth century, but it was Wollaston, the famous chemist and mineralogist, who rediscovered this property and turned it to his

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11 - Spurr, J. E., and Wormser, F. E., Chapter on Gem Stones, by G. F. Kunz; Marketing of Metals and Minerals, New York, 1st ed., 1925, p. 347.

own profit early in the nineteenth century by purchasing large stones of awkward shape or flawed inside and selling them back to the lapidaries after cleaving them into suitable forms. The older diamonds came from India and Borneo. Not until 1721 wore Brazilian stones positively identified, although diamonds may have been discovered in the gold washings as early as 1670,[12] and it was in 1867 that diamonds were discovered in South Africa. Carbonado or black diamond seems first to have been produced after the discovery of the Serra da Cincora field in Bahia in 1844.[13] Prior to the introduction of the diamond drill, however, these carbons were of little value and were used only in powdered condition for cutting and polishing brilliants and semiprecious stones. The first recorded use of diamonds for rock drilling was by Professor Rudolph Leschot[14] in 1863. The diamond drill did not come into general use, however, until 20 years or more later.

MODE OF OCCURRENCE

The diamonds of commerce have all been of natural origin. Henri Moisson, the famous French chemist (1852-1907), produced small diamonds under enormous pressure as a result of quickly solidifying carbon-saturated iron but these classic experiments, some 200 in number, cost more than $2,000 and yielded only one-half carat of diamond powder worth perhaps $1. In 1904, one Henri Lemoine, claiming to have manufactured diamonds by a secret process, succeeded in interesting Sir Julius Wernher, of the De Beers company. After advancing sums reputed to exceed $300,000 Sir Julius became suspicious and brought suit against Lemoine. During the trial Lemoine asked for an opportunity to give a demonstration, and during April, 1908, was released on bail for this purpose. After making elaborate preparations, however, he not only failed to produce artificial diamonds but forfeited his bail and fled. A sealed envelope, alleged to contain his secret, was later opened and found to contain a jumble of recipes of no value.[15]

The origin of diamonds is not clearly established. A large part of the world supply has been won from alluvial diggings, associated with various minerals commonly considered as originating in granitic rocks or veins in such rocks. Diamond has been noted in meteorites. The South African diamonds occur in conjunction with an eruptive peridotite, known as Kimberlite, which forms pipes or cylindrical masses inclosed in walls of nearly horizontal black carbonaceous shale. The formation is much like the core of an extinct volcano. Occurrence in Arkansas and in fact wherever the diamonds are found outside of transported sands and gravels (or sedimentary formations consolidated therefrom) are likewise associated with basic, eruptive rocks of similar character.

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12 - Kraus, E. H., and Holden, E. F., Gems and Gem Materials: New York, 1925, p. 111.

13 - Smith, G. F. Herbert, Gem-Stones: London, 2nd ed., 1913, p. 138.

14 - Patrick, R. S., Patrick Carbon (Catalog): Duluth, Minn., p. 11

15 - Sterrett, Douglas B., Precious Stones: U. S. Geol. Survey, Mineral Resources of the United States, 1907, pt. 2, 1908, p. 809.

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MINING

Diamonds, being appreciably heavier than most of the minerals with which they are associated, are recovered from alluvial deposits by washing, much in the same manner as gold. Hand panning is practiced in many localities.

In the Kimberley district the diamond-bearing rock was decomposed and quite soft near the surface and the diamonds were easily recovered by washing. As the workings became deeper, however, unweathered material or "blue ground" was encountered. For a long time it was the practice to remove this blue ground from the mines and pile it up in open fields or floors until it was softened by atmospheric agencies. Subsequently it was found that it was more economical to crush the hard rock rather than to tie up capital during the long period required for natural weathering to take place. Details of present practice are given in a paper by Alpheus F. Williams, general manager, and John Harbottle, consulting mechanical and electrical engineer, De Beers Consolidated Mines (Ltd.). The following abstract of this paper appeared in the South African Mining and Engineering Journal of April, 1930 (p. 109.):

> The blue ground containing diamonds occurs in vertical pipes of igneous origin. The horizontal cross sections of these pipes are irregular in shape, and the depths of the pipes have been unfathomed. Mining operations to-day are carried on some distance below ground level and as the blue ground has been removed from the pipe, the country rock above, being somewhat friable, has tended to assume a shape consistent with the natural angle of repose. The consequence is that all the mines have the well-known funnel shape at the surface, and the thousands of tons of country rock which have become detached to produce this shape have slipped into the pipe and rest upon the top of the blue ground below. The weight of this superimposed mass is made use of in the mining operations, as will be described later.
>
> At each mine a vertical shaft of rectangular shape and having five compartments is sunk at a distance from the edge of the pipe sufficiently far to ensure it permanence and stability. This distance is in the neighborhood of one thousand feet. From this shaft, a main rock tunnel is driven until it strikes the near side of the blue ground in the pipe. The tunnel up to this point is wide enough to accommodate two tracks for the haulage of the trucks to and from the shaft, with the additional provision of a travelling way for persons. The tunnel is continued right through the blue ground until it reaches the far side of the pipe, but this portion is narrower, as the empty trucks only are hauled through the pipe. This narrowed tunnel is driven on an upgrade so arranged that when the empty trucks reach the far side the increase in elevation is such that they when released will gravitate, either to the right or to the left, along a tunnel driven completely round the pipe, until they again reach the main rock tunnel. The grades of these latter tunnels are such that by the application of hand-operated retarders the speed of the trucks at any point does not become excessive. Each truck at some point of

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its gravitational run is stopped at one or other of the loading boxes, is there filled with mined blue ground and then started on its way again. When it reaches the main rock tunnel it is attached to the haulage rope and transported to the main shaft.

Each main rock tunnel serves to remove all the blue ground lying in the pipe above it for a height of six hundred feet, and some time before that blue ground is exhausted the main shaft is sunk to an additional depth of six hundred feet, a new main rock runnel is driven at that level and preparations made for the removal of another six hundred foot slice from the pipe. In the meantime development work has been proceeding in this lower section in the form of drifts or cross cuts, and this is accomplished from a subsidiary shaft sunk in rock close to the edge of the pipe, its upper or flat-sheet level being connected with the main rock tunnel for the time being in use.

The Recovery of the Diamond from the Blue Ground

General.--Kimberley blue ground contains approximately one grain of diamond per ton of ground, or one part in fourteen millions, and the recovery of this small content is the problem which has to be faced. Generally speaking, the diamond is embedded in the blue ground without much adhesion thereto, so that if the blue ground is broken up or disintegrated the diamond readily leaves its matrix and is loosely contained in the disintegrated mass. The first operation, therefore, is to reduce the blue ground to a size small enough to ensure the separation of the diamond. This is accomplished by crushers and rolls such as are common in many processes; but added care is taken in order to prevent diamonds being broken in the process. Up to a point, subsequent recovery depends upon the fact that the diamond is of a higher specific gravity than the ground with which it is associated. The first concentration is effected by passing the ground to which water is added through washing pans, details of which are given later. In these pans all the lighter material is washed away and sent to the waste dump and a heavier concentrate containing the diamonds and equal to approximately two per cent of the total weight handled settles at the bottom of the pans and is recovered. This concentrate is further reduced by passing it over pulsator jigs which are able to differentiate more closely between the weight of the diamond and that of accompanying material than was possible in the washing pan. Incidentally it may be mentioned that blue ground contains a percentage of other substances whose specific gravities approximate that of the diamond. The pulsator jig rejects all but that which has a weight nearly approaching, or greater than, that of the diamond. At this stage concentration by difference in weight ceases.

The heavy concentrate from the pulsator jigs is extracted and then fed on to inclined tables which have their surfaces smeared with grease. These tables, which are hung on flexible supports, are oscillated sideways by means of eccentrics, and have water running down their inclined surfaces. Of all the materials fed on to the grease table, the diamond--which adheres instantly--is the only one which is trapped. Other material which had accompanied it during the whole process is washed down and over the end of the table and is sent to the waste dump. The diamonds are won by scraping off the grease, which is melted down.

PREPARATION FOR MARKET

Diamonds are sorted at the mines, and each grade is made up into parcels, but a more careful grading is made at the cutting establishment or wholesale dealer's. Each stone is accurately weighed and examined by an expert who classifies it according to size and quality. Even parcels of gem stones may contain pieces that are reclassified as bort, and additional quantities of bort are obtained in the process of splitting and cutting gem stones. Ordinarily the weight of a cut gem is only about one-half that of the original stone, and much of this loss reappears in the form of crushing bort or dust.

Carbonado likewise has to be graded with skillful care. The larger stones are split and the fragments are re-graded according to size and quality.

Most of the larger dealers, in addition to purchasing stones and regrading them for sale, engage in the manufacture of diamond-tipped tools of various sorts. The mounting of the points is an art in itself and can be done properly only by an expert.

WORLD PRODUCTION

Practically the entire world supply of carbonado comes from the State of Bolivia in Brazil. Production in 1930 from this region was estimated at about 23,500 carats, valued at the mines at $1,350,000 United States currency. This area also produced 22,000 carats of white diamonds valued at $450,000, mostly small stones usually produced as a by-product of the black diamond output.

Data as to the production of bort and ballas are wholly lacking, but it is undoubtedly many times larger than the output of carbons. In view of the considerable wastage in trimming and cutting gem stones and the larger number of rejects, it is quite possible that approximately 40 per cent of the weight and from 10 to 15 per cent of the value of the world's total diamond production finds its way into industrial uses. Based upon the 3-year average output for 1927-1929, this estimate places the approximate production of industrial diamonds for that period in the vicinity of 2,500,000 metric carats or almost 100,000 pounds avoirdupois.

DOMESTIC PRODUCTION AND DEPOSITS

The United States, although one of the largest consumers of industrial diamonds, has not as yet been a significant factor in supply. Since 1906, an

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area in Arkansas has been proved to contain diamond-bearing rock in place and this State has already furnished several thousand carats, including many excellent stones, but elsewhere there have been only a few sporadic finds, none of which have been traced to any well-defined source. Kimberlite occurs in and near Syracuse, N. Y., and in Elliott County, Ky., but except for a single stone found in the former locality, there is no evidence that either of these occurrences is diamond-bearing. Individual, apparently isolated, stones have been picked up at long intervals along the eastern slopes of the Appalachians in North and South Carolina, Georgia, and Alabama. As long ago as 1855 a laborer working on street excavations in Winchester, Va., found a diamond weighing close to 23 carats in the rough and 11 carats after cutting. Though badly flawed and poor in color, it brought a good price as a gem stone. In North Carolina, a little boy sent to fetch water from a spring brought back a bright pebble that now reposes in the diamond collection of the American Museum of Natural History in New York. In Kentucky and Tennessee, likewise, a very few finds have been reported. Several stones have come from Idaho and Montana, and at Philadelphos, Ariz., a magnificent brown specimen weighing 1 carat was discovered. Placer mines in California are another source of an occasional diamond, mostly in the neighborhood of Fiddletown and Volcano in Amador County. In the Great Lakes region—Wisconsin, Michigan, Illinois, and Indiana—a comparatively large number of fairly big stones have been found in the glacial drift. It is believed that these stones originally came from somewhere in the desolate country to the south of Hudson Bay.[16]

The Arkansas diamond field is in the vicinity of Murfreesboro in Pike County. The characteristic peridotite rock is exposed in four places, covering in all about 80 acres, and in three of these places diamonds have been found. At least five mines have been operated: the Arkansas, the Ozark, the Mauney, the American, and the Kimberlite. The geology of the area has been well-described by Miser and Ross,[17] who comment as follows upon the size and quality of the stones:

> The diamonds that have been found range in weight from a very small fraction of a carat to many carats. Some are so small that 250 of them would be required to weigh 1 carat. The largest diamond, which was found in the Arkansas mine in the summer of 1924, weighed 40.23 carats; one weighing 20.25 carats was found in the Arkansas mine in September, 1921, and one weighing 17.86 carats was found in the same mine in May, 1917. The average weight of the 3,000 diamonds that had been produced by the Arkansas mine at the end of 1920 was about 0.4 carat, but the average weight of the diamonds that make up the entire product of all the mines is probably between 0.3 and 0.4 carat.

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[16] - Blank, E. W., Diamonds in the United States: Rock and Minerals, vol. 4, No. 2, June, 1929, p. 37.

[17] - Miser, H. D., and Ross, C. S., Diamond-Bearing Peridotite in Pike County, Arkansas: U. S. Geol. Survey Bull. 735, 1923, 336. pp.

Most of the diamonds are white, brown, or yellow. According to Kunz and Washington, there is a large proportion of white stones, most of them of a high grade in color, brilliancy, and freedom from flaws. These authors also say that many of the stones are as fine as any that have been found elsewhere, and that some of the yellow ones are of exceptional quality and color. In describing several yellow, brown, and white stones from the Arkansas mine Kunz says: "These are absolutely perfect and are equal to the finest stones found at the Jagersfontein mine, or that were ever found in India."

Commercial developments and mining operations are thus reported by Blank:[18]

> The Arkansas mine has been the chief producer, having recovered about 3,000 diamonds up till the end of 1920. The mine was again operated in 1921 for a short length of time but production figures are unavailable. The Ozark mine ranks second in production having yielded 800 to 900 diamonds in 1913. It was again worked from 1914 to January, 1919, but as in the former case the production is likewise unknown. Most of the diamonds are being held by the mining companies but estimates of the total number produced range from 5,300 to approximately 10,000 stones.
>
> The Arkansas Diamond Corporation, successor to the Arkansas Diamond Company, recovered from the Arkansas mine a total of 2,544.39 carats from April, 1923, to June, 1925. At a value of $5.00 per carat, the total production for this period of time is valued at approximately $12,721.
>
> Most of the mining has been done in shallow open cuts and the diamonds recovered by washing the diamond-bearing material with water. Much of the peridotite is already weathered and is soft enough to be washed for the recovery of the diamonds without being crushed or aged. The concentrates obtained by the washing are carefully searched for any large diamonds and then washed by water over a tray coated with thick grease. The greased tray is gently rocked during the process of washing and the diamonds stick to the grease, while the rest of the minerals are washed away. The grease with its diamond content is removed from time to time and the diamonds freed by boiling with strong lye.
>
> Amethyst quartz of gem quality is occasionally found associated with the diamonds. Dense chalcedonic novaculite is also found and some has been cut for use as jewelry.

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[18] - Blank, E. W., Work cited, p. 39.

IMPORTS

Statistics are available for the imports of industrial diamonds under three classifications: (1) bort, (2) diamond dust, and (3) glaziers', engravers', and miners' diamonds, unset.

Diamond dust and bort are derived principally from France and England. For five pre-war years (fiscal years, 1910-14), the average value of these imports (not separated prior to 1914) was $84,630 annually. The annual value of imports of "glaziers', engravers', and miners' diamonds, unset" for the same 5-year period ending June 30, 1914, averaged $299,908. Brazilian carbons constitute probably the largest item in this last group, but substantial amounts of material under this classification are imported from England, France, and the Netherlands and hence may include bort and more particularly bort specially prepared for the purposes designated. Ballas likewise comes under this classification.

Due to the possibility of including bort with glaziers' and miners' diamonds it is unwise to draw definite conclusions from the statistics with regard to the relative amounts of bort and carbons imported, but the evidence tends to show a substantial and fairly regular increase in the importation of Brazilian carbonado and a much smaller increase in the imports of diamond dust and bort. Large quantities of bort were imported immediately after the World War, but since 1926 the value of the amounts imported under that category has been scarcely as large as those recorded in pre-war years, whereas the value of the imports of glaziers', engravers', and miners' diamonds has apparently increased at least tenfold.

Statistics under the three classifications for recent years follow:

Imports for consumption of industrial diamonds into the United States, 1918-1930

Calendar years	Bort		Diamond dust		Glaziers', engravers', and miners' diamonds, unset	
	Carats	Value	Pounds	Value	Carats	Value
1918	1/	$ 460,237	1/	$ 15,633	1/	$ 1,049,975
1919	1/	1,367,088	1/	53,354	25,279	984,381
1920	1/	3,328,371	1/	59,117	61,214	1,527,753
1921	1/	440,013	1/	26,332	13,530	435,872
1922	1/	2/1,029,261	1/	3/	36,668	839,882
1923	1/	2/ 228,409	1/	3/	32,907	1,065,834
1924	22,908	217,944	49	41,538	32,463	1,116,862
1925	104,247	731,060	128	29,416	46,556	1,976,640
1926	17,690	207,966	1/	63,416	41,475	1,939,735
1927	1,747	33,786	1/	28,259	34,526	2,148,275
1928	996	17,949	1/	13,273	38,342	2,756,895
1929	4,567	73,200	1/	16,163	46,949	4,067,674
1930	5,119	86,036	1/	4,909	145,862	2,756,630

1/ Quantity not recorded.
2/ Value of dust and bort, not reported separately.
3/ Included with bort.

TARIFF HISTORY

Glaziers', engravers', and miners' diamonds, unset, have been specifically provided for on the free list of recent tariff acts. Diamond dust and bort, free under the tariff act of 1909, were made dutiable at 10 per cent of their foreign market value under the Underwood Act of 1913, and this rate was continued in the act of 1922. In the act of 1930 they were both returned to the free list (par. 1668) along with rough or uncut diamonds and other precious stones.

BRAZIL

Diamonds occur in Brazil over a wide area extending from Matto-Grosso to Bahia, crossing the States of Goyaz and Minas-Geraes, which is the center of the gem diamond industry. Carbons, however, occur almost exclusively in Bahia in a district known as Chapada Diamantina which includes Lençoes, Andarahy, and one or two other producing localities. Very few carbons are found in Minas Geraes. The Bahia carbonado, occurring in stream gravels along with gem diamonds, was first found in 1843, although up to about 1856 it was thrown aside as waste and was not of much importance prior to 1865.[19] True bort and ballas also occur in the Brazilian alluvial deposits. The output has been obtained by garimpeiros or native washers employing hand methods, depending mainly upon the batea. American and European firms maintain representatives in Bahia who purchase the stones from the small miners and occasionally take trips into the interior. Several years ago an attempt was made to work the deposits on a larger scale by employing mechanical methods, but it proved unsuccessful. In 1930, however, an Anglo-American company, after some years of preliminary work, completed a modern washing plant at Rio Paraguassú. After operating a few months, this plant was closed in November. It was reported that the suspension would be only temporary and that operations would be resumed.

Statistics showing the exports of diamonds and carbonados from Bahia during the past few years, as reported by Kunz,[20] are shown in the following table. These figures, however, are probably incomplete, as there is a certain amount of smuggling to avoid export duties:

Exports from Brazil

Year	Diamonds		Carbonados	
	Carats	Value	Carats	Value
1926	21,885	$ 390,580	21,313	----
1927	9,410	145,140	24,608	$ 1,526,000
1928	20,940	484,344	20,925	1,307,904

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19 - Ball, S. H., Industrial Uses of Diamonds: Eng. and Min. Jour.-Press, vol. 119, May 23, 1925, p. 847.

20 - Kunz, Geo. F., Precious and Semi-Precious Stones: Min. Industry. (Annual), New York.

Fully two-thirds of the exports are to the United States, which takes a much larger proportion--probably 90 per cent--of the better and more expensive stones. Export destinations are New York and Duluth in the United States, and London, Amsterdam, and Paris in Europe.

UNION OF SOUTH AFRICA

The value of the total output of diamonds in the Union of South Africa from the earliest records to the end of 1929 was officially reported at £294,780,750, of which 72 per cent was produced in the Cape Colony, 19 per cent in the Transvaal and 9 per cent in the Orange Free State. The average output for the 10-year period, 1920-1929, was 2,699,380 carats valued at £9,274,651. The smallest output for any year during the latter period was 669,559 carats in 1922 and the largest was 4,708,038 carats in 1927. The output of industrial diamonds is not stated separately, but it is commonly reported to exceed one million carats annually. An estimate of the relative proportions of the different classes of stones as prepared by Arend Brink, diamond valuator to the Government of the Union of South Africa, was published by Wagner.[21] The figures which evidently relate to about the year 1920, are as follows:

South Africa Diamond Classification

Grade	Per Cent of Total Yield	
	Quantity	Value
Close goods (blue white, fancy)	1.68	23.95
Irregular stones	0.20	6.39
Brown stones	6.00	12.96
Slightly spotted and spotted	3.50	19.62
Blocks and cleavage	10.28	27.70
Twin crystals and flats	9.44	8.57
Rubbish and bort	68.90	0.81
	100.00	100.00

The leading producer of bort is the Premier Diamond Mining Co. (Ltd.). Even this company's output, however, consists mainly of gem stones; in the fiscal year ended October 31, 1929, for example, the average value per carat produced was almost 25s. as compared with the fixed price of 7s. per carat for bort. At this property, the gross yield per "load" (about 1,600 pounds) of matrix washed has progressively declined to somewhat less than 0.2 carat; at times it drops to only 0.13 carat per load. Cost of production in the fiscal year 1929 was a trifle under 3s. per load, substantially higher than in the years immediately preceding. In other South African properties the yield per load varies from about 0.057 to 0.40 carat.

The following notes are abstracted from an article by Wagner:[22]

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[21] - Wagner, Percy A., The Diamond Industry of Africa: Abrasive Ind., vol. 4, August, 1923, pp. 227-230.

[22] - Wagner, P. A., Work cited.

***The productive diamond fields are scattered over a vast area of the subcontinent of South Africa between 5 and 31° south latitude. The diamond, as might be expected, is found under the most diverse conditions, the principal modes of occurrence being in pipes and dikes, ancient conglomerates, tertiary conglomerates and in tertiary and recent stream gravels. In pipes and dikes diamonds occur in a peculiar porphyritic peridotite, known as kimberlite, which is always in a more or less advanced state of serpentinization. The kimberlite pipes are by far the most important source of production. They are deeply eroded volcanoes of the explosive type occupied partly by serpentinized kimberlite, partly by kimberlite tuff and breccia and partly by material derived from rocks pierced by the pipes. From the surface to a depth of from 35 to 140 feet the pipe filling has generally been converted by hydration and oxidation into a soft, yellowish, clayey rock known as yellow ground. Below it follows a zone of hydrated, but not oxidized rock which, from its peculiar greenish or greyish blue color, is known as blue ground. This in turn is succeeded by comparatively well-preserved kimberlite or hardebank, as it is termed on the mines.

While such pipes are scattered over an enormous area of the plateau tract of southern Africa, the economically important occurrences are confined to a fairly well-defined diamond belt extending in a northeasterly direction from Jagersfontein in the Orange Free State to the Premier mine in the Transvaal, a distance of some 350 miles. ***

In Tertiary conglomerates the stones occur in grits and sandstones, and eluvial gravels derived from their disintegration. The deposits in the coastal desert of South West Africa, which have become so important a factor in the diamond industry, illustrate these types of occurrence. There has been a great deal of speculation regarding the origin of the South West African diamonds. Recent investigations prove that in part, at any rate, they were brought down to the littoral by ancient rivers, in the gravels of which they became imbedded. From these, through erosion they found their way into Miocene and later sediments accumulating along the coast, the distribution of the diamonds having probably been effected by the agency of the Benguella current. Upon the uplift of the coast these rocks were subjected to desert weathering and in considerable part destroyed, a portion of the diamonds being thereby liberated and concentrated in residual surface gravels. The diamond has thus suffered several transportations and concentrations, with the result that some of the eluvial gravels are of fabulous richness.

In Tertiary and recent stream gravels belong the extensive deposits in the basins of the Vaal, Harts and Orange rivers, and the even more extensive deposits situated in the basin of the Kasai river in the northeastern corner of Angola and the adjoining areas of the

Belgian Congo. In both areas, stream and terrace gravels are worked, some of the gravels occurring at elevations of over 400 feet above the present river channels.

For the exploitation of the kimberlite pipes and some of the productive dikes, elaborate methods of opencast and underground mining have been evolved. The deepest workings are at Kimberley where mining operations have been successfully conducted at depth of over 3500 feet. ***

Union of South Africa Diamond Sales, showing Average Price per Metric Carat Obtained[1]

Year	Mine stones		Alluvial stones		All stones	
	s.	d.	s.	d.	s.	d.
1911	32	1	108	3	34	2
1912	36	5	104	11	39	1
1913	40	1	105	11	42	6
1914	37	5	78	1	39	2
1915	45	9	78	3	51	6
1916	39	3	110	3	44	5
1917	44	9	110	11	49	9
1918	48	11	131	0	53	4
1919	85	0	254	9	98	5
1920	99	9	213	3	113	11
1921	64	8	117	8	79	5
1922	46	10	133	4	61	2
1923	51	11	135	9	59	10
1924	52	6	149	7	66	2
1925	57	4	159	5	66	8
1926	58	11	98	7	69	0
1927	58	0	53	6	55	7
1928	45	4	83	7	60	2
1929	67	1	96	7	80	8

[1] Union of South Africa, Dept. of Mines and Industries, Annual Report, 1930, p. 36.

MARKETS AND PRICES

In no other industry has production been so closely proportioned to demand as in diamond mining. The Government of the Union of South Africa exercises complete control of diamond production and levies a heavy tax on the output of each mine. It prohibits prospecting for new deposits and takes measures to prevent mining by unrecognized operators. It is itself a producer of diamonds in the Government-owned mines in Namaqualand.

The control of the diamond market has been maintained largely as a means of protecting the reputation of gem diamonds as investments, but it extends also to bort and other diamond material produced by its members and employed for industrial purposes. It does not extend to Brazilian carbons, a field in which the problem many times has been to get enough material rather than to restrict production. Even in this industry the number of firms that operate at the source of supply or maintain buying offices in Brazil is not large. There has been little or no concerted action on the part of these firms to cooperate and at times the trade has suffered because of competitive bidding resulting in sharp increases in prices, particularly of high-grade stones.

The workings of the control system as it governs the marketing of industrial white diamonds or bort are well described in the annual market letter of one of the large dealers for 1926:[23]

> Industrial White Diamonds (Boarts). - During 1926 the market for industrial diamonds was fluctuating. The policy of the Diamond Syndicate was not to put more diamonds on the market than could be consumed, and it even supplied less in order to create a certain scarcity. Although in the United States the motor-car industry, which is the largest consumer in the industrial diamond world, produced about 30 per cent more cars, the sale of industrial diamonds decreased heavily, which proves that substitutes and special care in using the diamonds reduced the consumption considerably. During the first part of the year prices decreased on account of small demand. When the Common Goods Combination, which buys the whole output of the combined diamond mines, came into the hands of one man, many dealers bought up all the goods available on the open market, and therefore created firmer prices, whilst no new goods were placed on the market.
>
> It has been the Syndicate's policy to raise the price for crushing boart, as the price of this material influences the prices for common industrials and low-quality cleavages for polishing, common brown diamonds, etc. The world's annual consumption of crushing boart is about 350,000 carats, and about 1,000,000 carats are found. The theory is that a high price for crushing boart is the best way to stabilize all the common articles. By reducing the price, the consumption would not become much larger, and by making high prices the unsold part of the output can then be written off. The combination adopted the system of buying up, at a certain price, all the crushing boart which was offered on the Amsterdam and Antwerp markets, and then raised the price, which was 12s. 6d.. per carat at the beginning of the year, to 16s. 6d. at the end of the year. There are five parties interested in this manipulation of crushing boart. To begin with, the producing mines have their difficulties amongst themselves, as in Angola alone they could produce 1,000,000 carats a year easily, and we are informed that they have bought the latest and best machinery, so that even at a sale

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[23] - Supplied by J. K. Smit & Zonen, of Amsterdam, Mineral Industry, 1926, pp. 567, 569.

price of 2s. 6d. per carat they could make their mining profitable. Secondly, the Syndicate, getting the whole output of the combined mines, must accumulate the common diamonds and crushing boart to millions of carats, as they sell only 1 carat out of 3. By making a high price for this 1 carat they create a cheap reserve (their fighting force), thus preventing what happened in a past year, when the producing mines received an offer from another trust. Thirdly, the Common Goods Combination must also have an accumulation of common industrials, for which there is little demand. They, therefore, adopt the same policy. Fourthly, the independent dealers are not willing to take the burden from the other parties' shoulders, as they know too well that the risk at these fictitious prices is too great in comparison with the comparatively small profit made on these articles. Fifthly, the consumer, not being able to defend himself in this matter, will only use as little as possible and only buy the amount he actually needs.

Industrial diamonds, though much less costly than the varieties used for jewelry, are nevertheless worth a great deal in proportion to their bulk. Transportation charges play little part in the final cost and it is quite common to send packages of stones to a prospective customer, permitting him to make his own selections and return those that he does not want. Special precautions are taken to provide for safety in transit and blanket insurance policies are obtainable which protect the dealer against loss.

The unit of weight in industrial as well as gem diamond transactions is the carat. Originally this was the weight of a carob seed, and even in recent times the weight varied in different gem centers. In Madras it used to be 0.2073 gram; in Amsterdam, it was 0.2057 gram; in London, 0.2053; in Florence, 0.1972; and so on. In 1871 an attempt was made to establish as the standard an "international carat" of 0.2050 gram. Later the metric carat of 0.200 gram was proposed and this logical figure soon became the recognized standard in the principal countries of the world. It was officially adopted in the United States in 1913.

It is utterly impossible to make any simple statement with regard to prices. In 1931, crushing bort had dropped to $1.60 a carat, as compared with $2 a carat in 1928 and about $4 in 1925. According to Ball,[24] diamond dust, immediately prior to the discovery of the South African mines, was worth from $1.20 to $4 a carat, but with the opening of these mines the supply was increased and consequently prices broke. By 1902 the prices had climbed back to $2 only to slump again following the discovery of the Premier mine in 1903. In 1909 the price was down to 75 cents a pound, but eventually it rose again to $4 after the World War. The price of crushing bort is controlled at the source by the Diamond Syndicate. A few years ago it was being held at 17s. Later it dropped to 12s. 6d., but there was an advance to 16s. 6d. toward the end of 1926. In 1929 the price was held at 7s. a pound throughout the

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24 - Ball, S. H., Work cited, pp. 848-9.

year, but in September, 1930, competition from West Africa combined with the reduced demand precipitated a reduction to 5s. 9d. Subsequently, there have been only minor fluctuations.

The price of bort other than crushing bort depends upon both the quality and the size. In 1931, small white industrial diamonds were worth $12 to $15 a carat. Brazilian bort, being harder, brings a higher price than Cape bort. Shape, structure, soundness, and color also enter into the value and the situation is further complicated by fluctuations in the demand for various sizes. Large industrial borts, weighing from 2 to 10 carats, form a different class from smaller sizes. Flat bort, used for wire drawing, constitutes another specialty. The majority of glaziers' diamonds come from Brazil or Borneo and are sold at a relatively high price.

In 1929 the price of carbonados reached £32 10s. per carat in Brazil, but this unprecedented price stimulated substitution of white diamonds, particularly for diamond drilling, using the new multi-stone crown. Prior to the extensive employment of the diamond drill for prospecting, carbons were of little value. It is said that for a time they were shipped to Amsterdam in barrels and sold for 1s. a carat. In the eighties they were generally worth less than $10 and it was not until after the World War that they advanced much beyond $100 a carat. In 1931, carbons were selling all the way from $10 to $150 or $160 a carat, depending in part upon size. Moderately large stones, 2 carats and over, were worth on the average about $145 a carat. Stones weighing 1 carat each were selling for about $100 a carat, 3/4 carat stones were quoted in the neighborhood of $75 a carat, and so on, the price per carat diminishing with the weight of the individual stones.

DEALERS IN INDUSTRIAL DIAMONDS

R. S. Patrick, Duluth, Minn.
Bernard Bandler & Sons (Inc.), 8 W. Fortieth St., New York, N. Y.
Fink & Fink, 36 W. Forty-seventh St., New York, N. Y.
Abraham Levine, 2 Maiden Lane, New York, N. Y.
Minerals & Insulation Corporation, Broome & Green St., New York, N. Y.
U. S. Industrial Diamond Corporation, 475 Fifth Ave., New York, N. Y.
Van Itallie Co., 90 W. Broadway, New York, N. Y.
Diamond Tool Co., 123 W. Madison St., Chicago, Ill.
L. M. Van Moppes Diamond Co., 122 Clinton Ave., Newark, N. J.
David Davis, 505 Fifth Ave., New York, N. Y.
Hartley Wire Die Co., Box 698, Waterbury, Conn.
Swiss Jewel Co., Lafayette Bldg., Phila., Pa.
Philip Sinsz Co., 300 S. Hanover St., Baltimore, Md.
Holbrook Bros. (Inc.), 89 Beekman St., New York, N. Y.
Jas. H. Rhodes & Co., 153 W. Austin Ave., Chicago, Ill.
Diamond Tool & Die Works, Hartford, Conn.
Francis & Co., 50 State St., Hartford, Conn.
W. F. Meyers Co. (Inc.), Meyers Bldg., Bedford, Ind.
A. A. Crafts & Co., 125 Summer St., Boston, Mass.
Commercial Diamond Co., 3rd Floor, Boyer Bldg., Detroit, Mich.
Craine Diamond Co., 6209 Hamilton Ave., Detroit, Mich.
Diamond Detroit Tool Co., 1050 Mt. Elliott Ave., Detroit, Mich.
Modern Diamond Tool Co., 2481 E. Grand Blvd., Detroit, Mich.
F. Krause & Co. (Inc.), 252 Ogden Ave., Jersey City, N. J.
Koebel-Wagner Diamond Corporation, 144 Orange St., Newark, N.J.
Staset Co. (Inc.), West Orange, N. J.
Willard F. Meyers Machine Co., 33-35 Ninth St., Long Island City, N. Y.
Ballofeet Wire Dies Co. (Inc.), 15-17 E. Twenty-second St., New York, N. Y.
Maurice S. Dessau, 6-8 Maiden Lane, New York, N. Y.
Diamond Die Co. of America, 421 Seventh Ave., New York, N. Y.
Diamond Drill Carbon Co., 57 Park Row, New York, N. Y.
Thos. L. Dickinson, 36 Gold St., New York, N. Y.
E. Karelsen (Inc.), 17 W. Forty-fourth St., New York, N. Y.
Mendes Cutting Factories (Inc.), 105 W. Fortieth St., New York, N. Y.
Smit, Anton & Co. (Selma Mercantile Corporation, 24 State St., New York, N. Y.
Standard Diamond Tool Corporation, 40 W. Forty-seventh St., New York, N. Y.
Paul Steiner, 465 Eighth Ave., New York, N. Y.
Wheel Trueing Tool Co., 135 Fort St., W. Detroit, Mich.
John Wennstrom's Sons (Inc.), Suffern, N. Y.
Byron & Hall, 1441 Broadway, New York, N. Y.

CONSUMERS OF INDUSTRIAL DIAMONDS

Diamond Tool & Die Works, Hartford, Conn.
Francis & Co., 50 State St., Hartford, Conn.
Standard Wire Die Co., Waterbury, Conn.
Galconda Diamond Products Corporation, 711 W. Lake St., Chicago, Ill.
W. F. Meyers Co. (Inc.), Meyers Bldg., Bedford, Ind.
A. A. Crafts & Co., 125 Summer St., Boston, Mass.
Union Tool Co., Orange, Mass.
Commercial Diamond Co., 3rd Floor, Boyer Bldg., Detroit, Mich.
Craine Diamond Co., 6209 Hamilton Ave., Detroit, Mich.
Diamond Detroit Tool Co., 1050 Mt. Elliott Ave., Detroit, Mich.
Modern Diamond Tool Co., 2481 E. Grand Blvd., Detroit, Mich.
F. Krause & Co. (Inc.), 252 Ogden Ave., Jersey City, N. J.
William Dixon (Inc.), 3236 E. Kinney St., Newark, N. J.
Koebel-Wagner Diamond Corporation, 144 Orange St., Newark, N. J.
Staset Co. (Inc.), West Orange, N.J.
J. L. Osgood Machinery & Tool Co. (Inc.), 45 Pearl St., Buffalo, N. Y.
Willard F. Meyers Machine Co., 33-35 Ninth St., Long Island City, N. Y.
Acme Diamond Tool Co., 172 Broadway, New York, N. Y.
Ballofeet Wire Dies Co. (Inc.), 15-17 E. Twenty-second St., New York, N. Y.
Byron & Hall, 1441 Broadway, New York, N. Y.
Maurice S. Dessau, 6-8 Maiden Lane, New York, N. Y.
Diamond Die Co. of America, 421 Seventh Ave., New York, N. Y.
Diamond Drill Carbon Co., 57 Park Row, New York, N. Y.
Thos. L. Dickinson, 36 Gold St., New York, N. Y.
E. Karelsen (Inc.), 17 W Forty-fourth St., New York, N. Y.
Mendes Cutting Factories (Inc.), 105 W. Fortieth St., New York, N. Y.
Smit, Anton, & Co., (Selma Mercantile Corporation) 24 State St., New York, N.Y.
Standard Diamond Tool Corporation, 40 W. Forty-seventh St., New York, N. Y.
Paul Steiner, 465 Eighth Ave., New York, N. Y.
Tungsten Tool Co. (Inc.), 333 W. Fifty-second St., New York, N.Y.
Precision Trueing Machine & Tool Co., Front & Scott Sts., Cincinnati, Ohio.
Kelly Reamer Co., 3800 S. Seventy-third St., Cleveland, Ohio.
American Emery Wheel Works, Waterman and East River Sts., Providence, R. I.
Desmond-Stephan Mfg. Co., Urbana, Ohio.
Wheel Trueing Tool Co., 135 Fort St., W. Detroit, Mich.
E. W. Porter & Son, Punxsutawney, Pa.
John Wennstrom's Sone (Inc.), Suffern, N. Y.
Sullivan Machinery Co., 709 Wrigley Bldg., Chicago, Ill.
Sprague & Henwood (Inc.), 225 W. Olive St., Scranton, Pa.
Mott Machine & Mfg. Co., Huntington, W. Va.
Ingersoll-Rand, 11 Broadway, New York, N. Y.
Lake Shore Engine Works, Marquette, Mich.
E. J. Longyear Mfg. Co., Foshay Tower, Minneapolis, Minn.